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# Delineation of Salt Water and Fresh Water Interface between Kolleru Lake and Bay of Bengal Coast, Andhra Pradesh, India – Using Remote Sensing and GIS Techniques

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## Abstract

Kolleru Lake is the largest natural fresh water lake located between Godavari and Krishna deltas in Andhra Pradesh in India and is acting as a natural flood balancing reservoir. Dynamic land use changes from lake bed and agricultural land to aqua-culture and overexploitation of groundwater are becoming the major causes for salt-water intrusion. Changing of land use patterns is highly influencing on the quality of water. Paleo beach ridges are having potential aquifers around the Kolleru Lake. The main aim of this study is to identify seawater intrusion areas and reasons for intrusion. Integrated study of hydrogeology, hydrochemistry, remote sensing and geophysical investigations exposed the extent of salt-water intrusion up to the northern part of the lake, which is about 42 km away from the Bay of Bengal coast line. Top layer resistivity is more than 10 ohm-m in case of sand formations, 2–10 ohm-m in case of brackish water saturated formations and less than 1.0 ohm-m in case of saline water saturation aquifers, and clay-rich layers shows the resistivity in the range of 2 to 5 ohm-m. Remote sensing data and GIS (Geographical Information System) helped us to trace two major sea water intrusion patches from the coast to the lake.

**Keywords:** Kolleru Lake, saltwater intrusion, overly techniques, remote sensing and GIS

## 1. Introduction

Kolleru is one of the biggest shallow fresh water lakes in India which is located between the deltas of Godavari and Krishna Rivers of the Andhra Pradesh, India. The lake collects water by over 69 inflowing drains and channels. The catchment of Kolleru Lake is extends upto 9036.30 km<sup>2</sup>. The major occupation of the surrounding people is agriculture and fishing. Since last three decades aquaculture is developed inside the coastal area encroached into the agricultural lands and into the Kolleru

Lake also [1]. The main drinking water source to this area people is ground water. Potable groundwater is available in beach ridges in the range of 3–5 m depth and many houses having an open well. An endeavor is made to know the problem with multidisciplinary loom to propose some elucidation to develop the drinking water situation particularly the area between lake and the coast area.

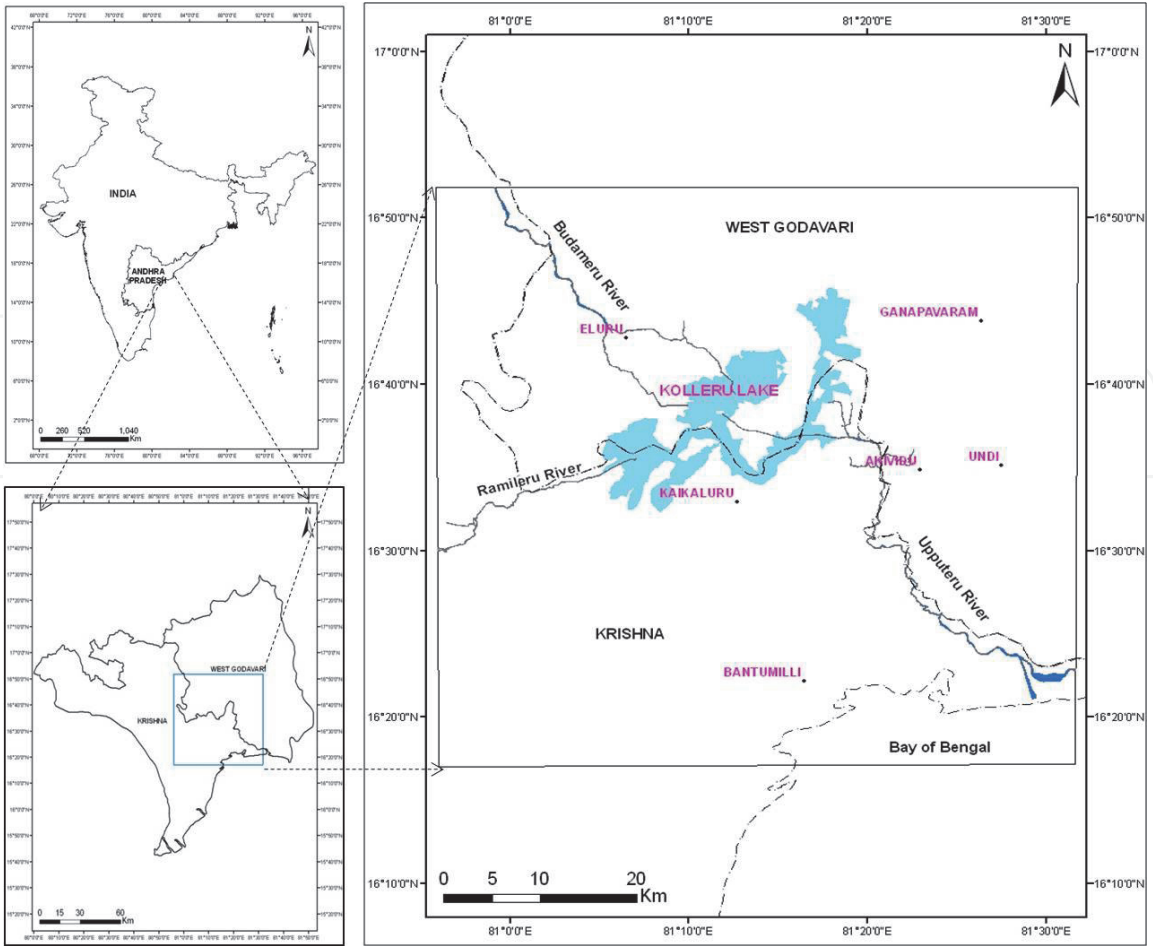
Prolonged water logging conditions during the active monsoon periods due to poor drainage is not uncommon. Especially in drought time these wetlands are the best source to ground water potential and will play a major role in flood control at the time of active monsoon. Over past six decades the shifting of fresh water lake to agriculture land; and agriculture to aquaculture; and finally finishing to the aquaculture demolition was driven by the demanded economic benefit surpassing ecological and social community growth. Saltwater intrusion is adulterated coastal aquifers predominantly in and around the Kolleru lake region, most of the farmers to get aquaculture as an extracommercial source of income, where salt water is used from the nearby creeks [2]. Saline or brackish groundwater is present below fresh groundwater in deltaic and coastal areas [3]. Due to overexploitation of groundwater in many parts of India and worldwide the coastal aquifers are generally fragile in nature and the shallow aquifers are easily depleted [4]. Remote sensing and geophysical, geochemical and GIS techniques are used to directly or indirectly supervise saltwater in coastal aquifers. However, high TDS (Total dissolved solids) concentration or specific conductance of groundwater samples are other indicators of groundwater salinity [5]. Electrical Resistivity survey is the best method to discriminate the sub-surface layers includes aquifers and to certain extent the quality of groundwater [6]. Through the spatial distribution of electrical conductivity, we can assess the presence of dissolved ions in a coastal aquifer [7].

## 2. Study area

The study area lies in between the delta regions of Krishna and Godavari rivers which covers 31 revenue blocks (Mandals) out of that 16 revenue blocks in West Godavari district and 15 revenue blocks in Krishna district of Andhra Pradesh, India. The total area covered in this study is about 3861.97 km<sup>2</sup> lying in between 80° 50' to 81° 39' E longitude and 16° 17' to 16° 59' N latitude. Location map of the study area is shown in **Figure 1**.

### 2.1 Geology

The study area is engaged by recent alluvium and forms a part of Krishna and Godavari deltas. Deltas are the results of the continuous supply of sediment by rivers to coasts and upper continental shelves. They make the largest latent places for the clastic sediments and the shape is mostly a lobe like extension of the coast with a number of divisions. The main axes of the delta run typical to the regional depositional strike. In general the area is occupied by clays, silts, silty clays and silty sands with variable thickness ranging from 1.5 to 3.5 m. These are under laid by sandy layers of variable thickness ranging from 1.5 to 4.5 m in the beach ridge regions and paleochannels. The deltaic plains are occupied by clays and silty clays and extend to a maximum depth of about 2 m. These clays are under laid by saturated clay deposits extending up to greater depths. Main geological features in this study area are active beach, flood plain, Gollapalli formation, Gollapalli/Chintalapudi sandstone, khondalite, Kolleru formation, Kolleru Lake, laterite, paleo beach ridges, paleo channel, paleo tidal flat, Rajahmundry sandstone and Tirupati



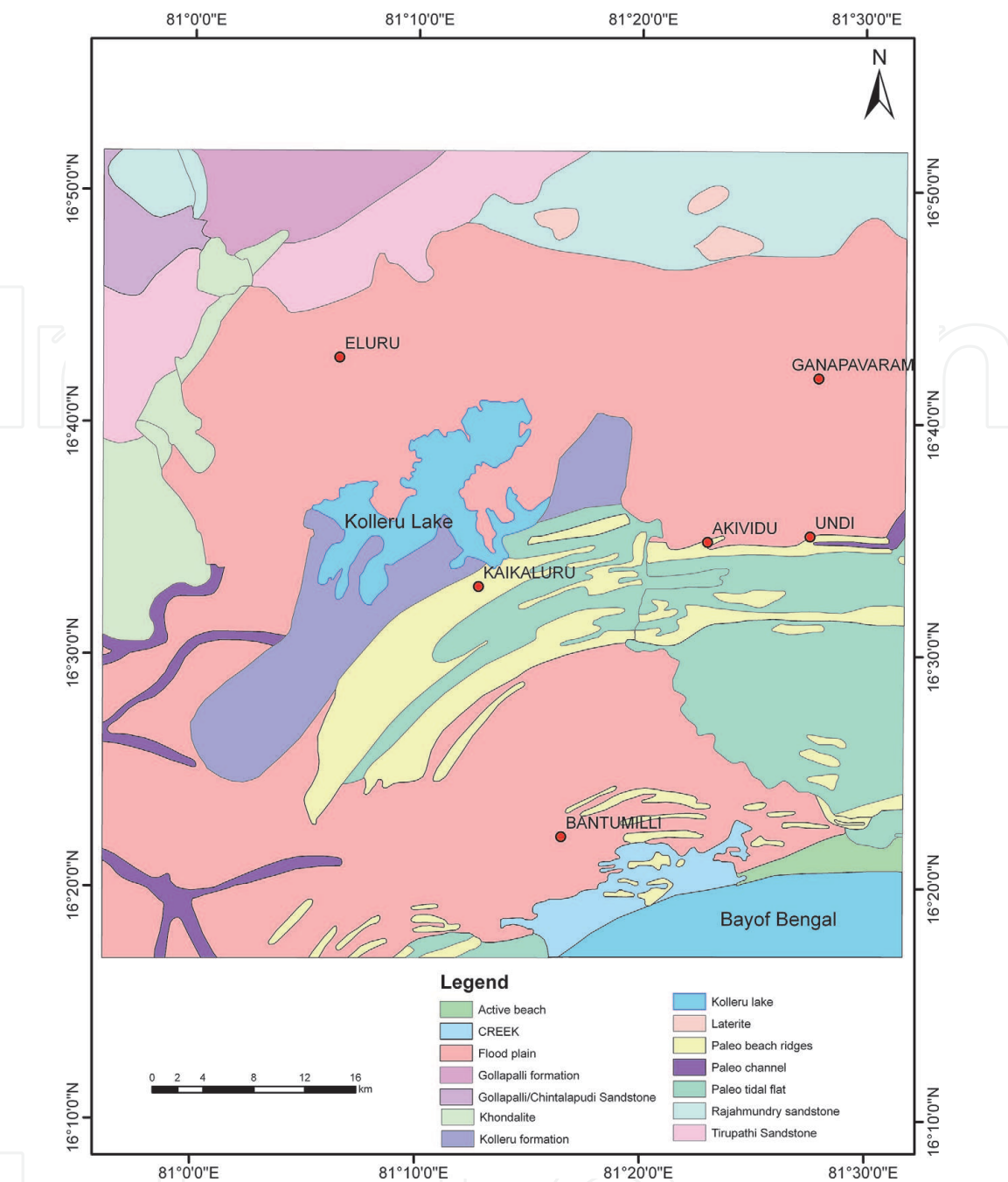
**Figure 1.**  
*Location map of the study area.*

sandstone and the geology map of the investigation area is shown in **Figure 2**. The geometry of the Kolleru-Upputeru catchment is guided by the regional lineaments. The most dominant directions of these lineaments are NW-SE and NE-SW. The density of fractures/lineaments is more in Archaean metamorphic rocks and Gondwanas of Chintalapudi sub-basin than East-coast Gondwanas and Rajahmundry sandstones. The structures in the area control the occurrence and movement of ground water.

### 3. Methodology

The methods adopted during the course of this investigation have been presented below. Standard scientific methods were used for laboratory investigation. The methodology has been presented as follows.

- Remote Sensing methods
- Integration of chemical data
- Electrical Resistivity survey
- Interpretation of field data and integration



**Figure 2.**  
Geology map of the study area.

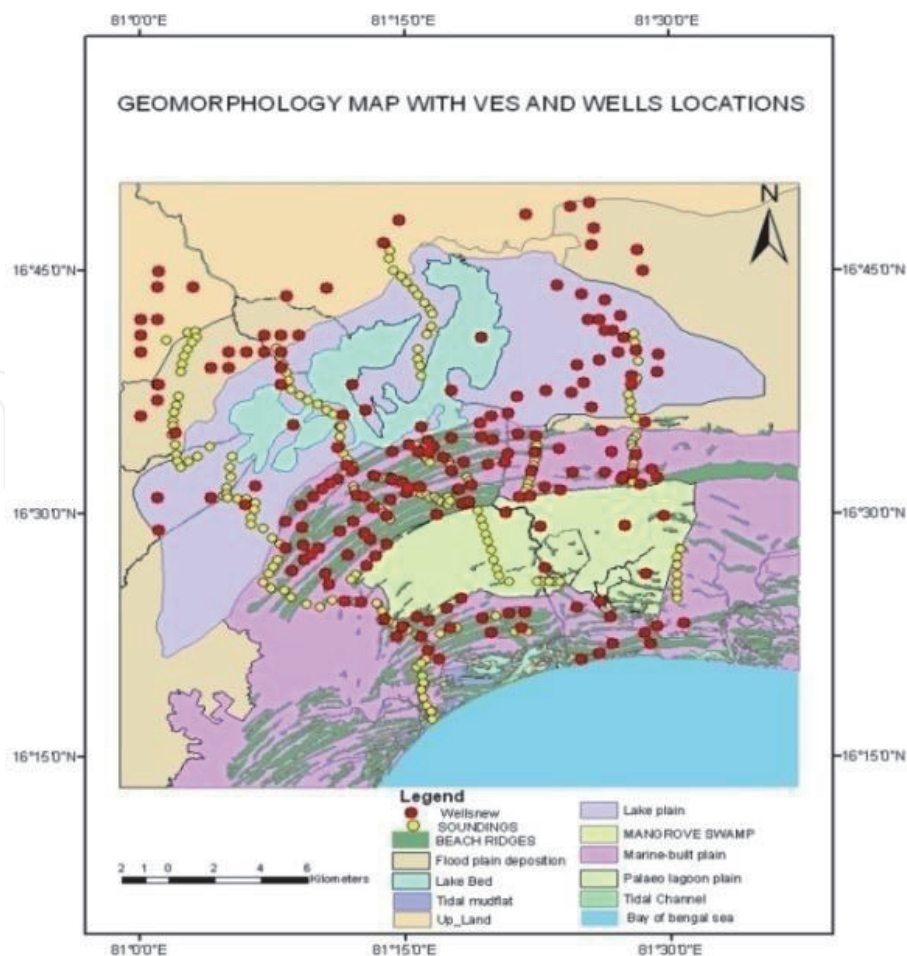
### 3.1 Remote sensing methods

Remote sensing has become the most powerful scientific tool for the study of various Earth resources and related features. The advent of colored satellite imageries has revolutionized the Remote Sensing activity. Survey of India toposheets of 1:50,000 scale maps were Geo-referenced then mosaic all the images in order and choose AOI (Area of Interest) with sub setting images (65D/13, 65D/14, 65D/15, 65H/1, 65H/2, 65H/3, 65H/4, 65H/5, 65H/6, 65H/7, 65H/8, 65H/9, 65H/10, and 65H/11) was done to extract the study area. IRS P6 LISS IV of March, 2014 digital satellite data is used for land use/land cover, geology and geomorphology studies.

#### 3.1.1 Geomorphology

The major geomorphological features are flood plain deposition, lake bed, beach ridges and marine built plains are shown in **Figure 3**. Ridges are having potable





**Figure 3.**  
*Wells and VES locations on geomorphology map.*

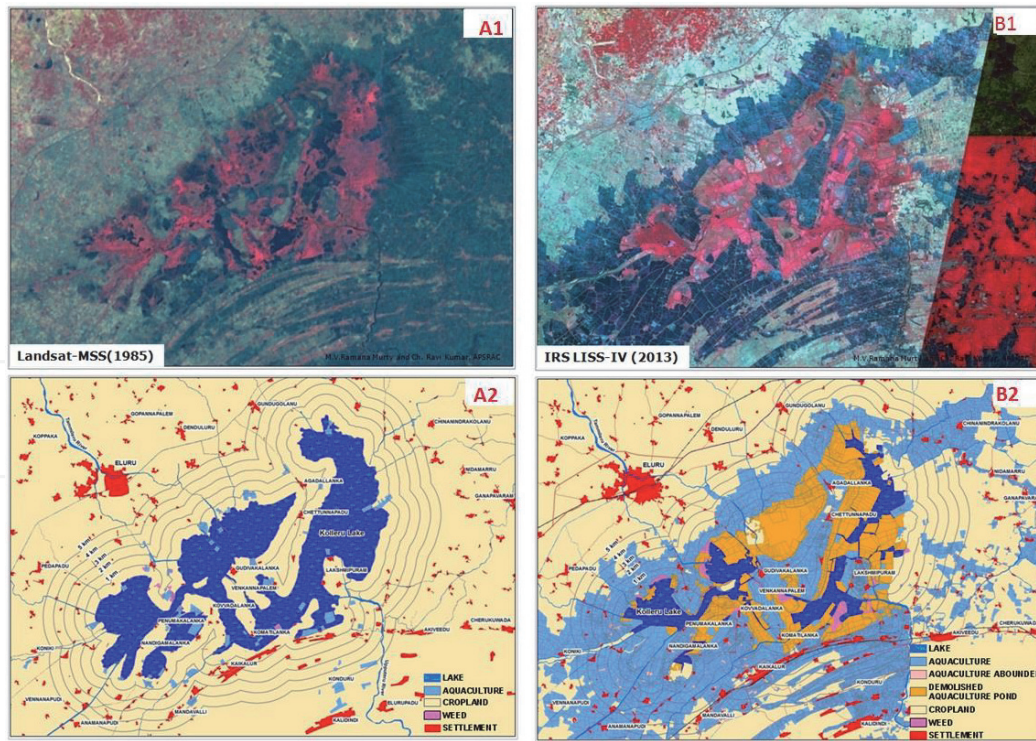
fresh groundwater and shallow areas are deposited with saltwater. Almost all five strand lines are indicated that beach is slowly move away from the lake since Holocene period.

### 3.1.2 Hydrogeology

Totally 175 wells were selected to observe the groundwater table fluctuations for three continuous year during the research period and collected 175 water samples which covers the total study area and the locations of these wells are presented on the geomorphology map as shown in **Figure 3**. Water levels are measured with automatic water level indicator and coordinates were measured with Global positioning system (GPS) and 50% of the wells indicated more than 3.0 m depth of water table during pre-monsoon period.

### 3.1.3 Land use/land cover dynamics

The land use/ land cover map evidently shows that agricultural land is higher than others shown in **Figure 4a**. But since two decades aquaculture is abundantly increasing (**Figure 4b**). The results shows that the Kolleru lake in and around has good aquaculture potential (27.91% of TGA aquaculture) and agricultural land is 60.72%(include plantations, fallow land and horticulture) total geographical area of the study area. The land use/land cover categories like extent of the lake, aquaculture, cropland, and built-up land are mapped for 1985 and 2013 “**Figure 4a and b**”. A buffer of 1 km interval is drawn from lake to 5 km. It is observed that the area under aquaculture within the lake has gradually increased (128 km<sup>2</sup>) till 2005.



**Figure 4.**  
(a) Dynamic land use changes within and around the lake during – 1985; (b) dynamic land use changes within and around the lake during – 2013.

### 3.1.4 Hydrology

The area is drained by five major hydrological systems that include Budameru, Ramileru, Tammileru, Gunderu and Errakalava of which the first four directly flow and let water into Kolleru whereas, Errakalava linked near to the mouth of Upputeru by construction of Enamadurru drain and thus falls into Upputeru Sub-catchment. These rivers are ephemeral in nature and flow in response to rainfall and are influent to effluent in nature. The hydrological system depicting the Kolleru-Upputeru catchment and their watersheds is shown in **Figure 5**.

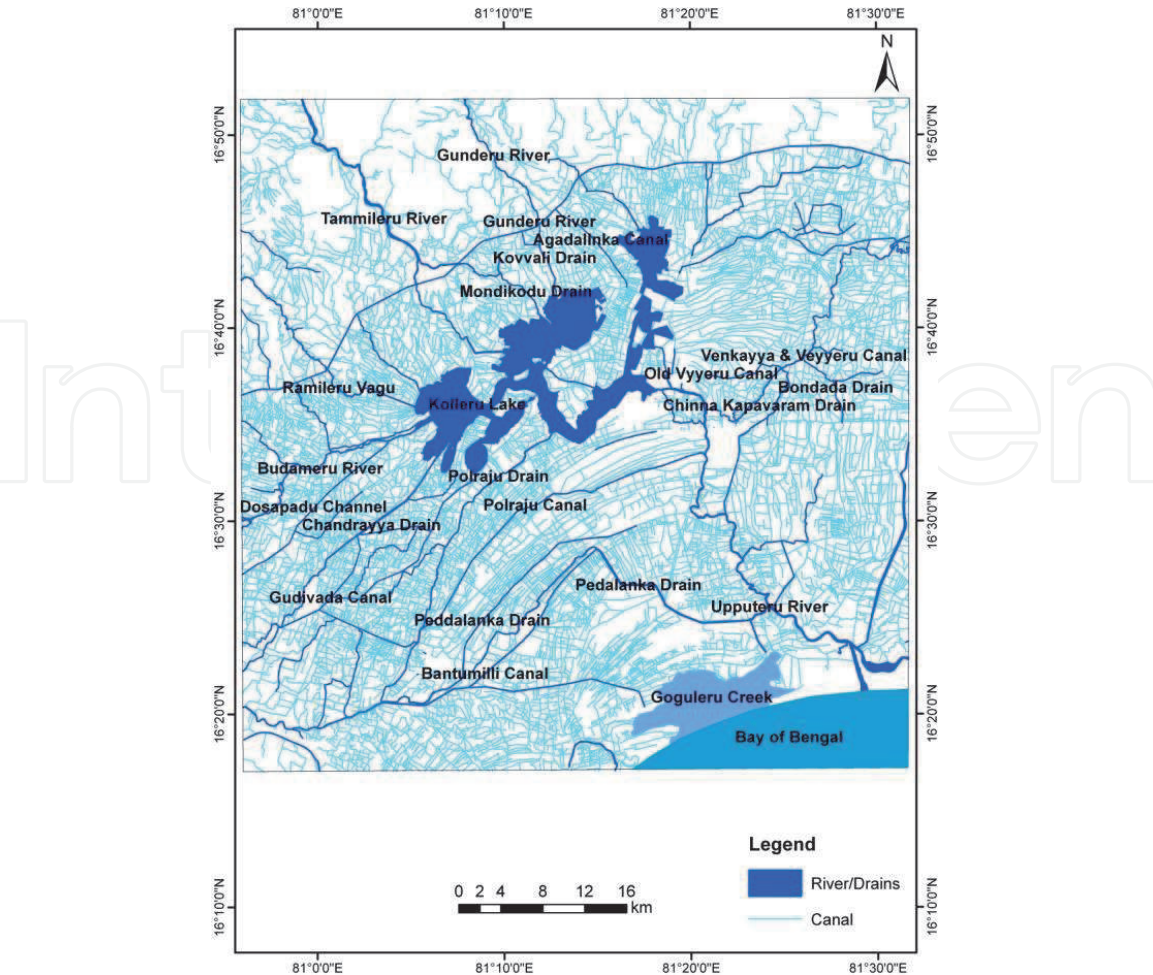
## 3.2 Integration of chemical data

Chemical parameters of groundwater samples are well explained above comparing the WHO and BIS standards [8, 9]. Broadly the areas of maximum desirable, maximum permissible and beyond permissible limits are demarcated. Red boundary line enclosure in **Figure 6** is highest TDS area. Same area with same geographical coordinates superposed over the thematic maps of all over the other 8 parameters like Electrical conductivity, salinity, Chlorides, Sodium, Hardness, Potassium, Calcium and Magnesium. **Figure 6(a)** is the areal distribution of TDS and **Figure 6(b)** is the aerial distribution of Ca over which the border line of beyond allowable limit of TDS is super posed. Similarly TDS is superposed over the other six parameters. Surprisingly all the chemical parameters high concentration is showing in two patches.

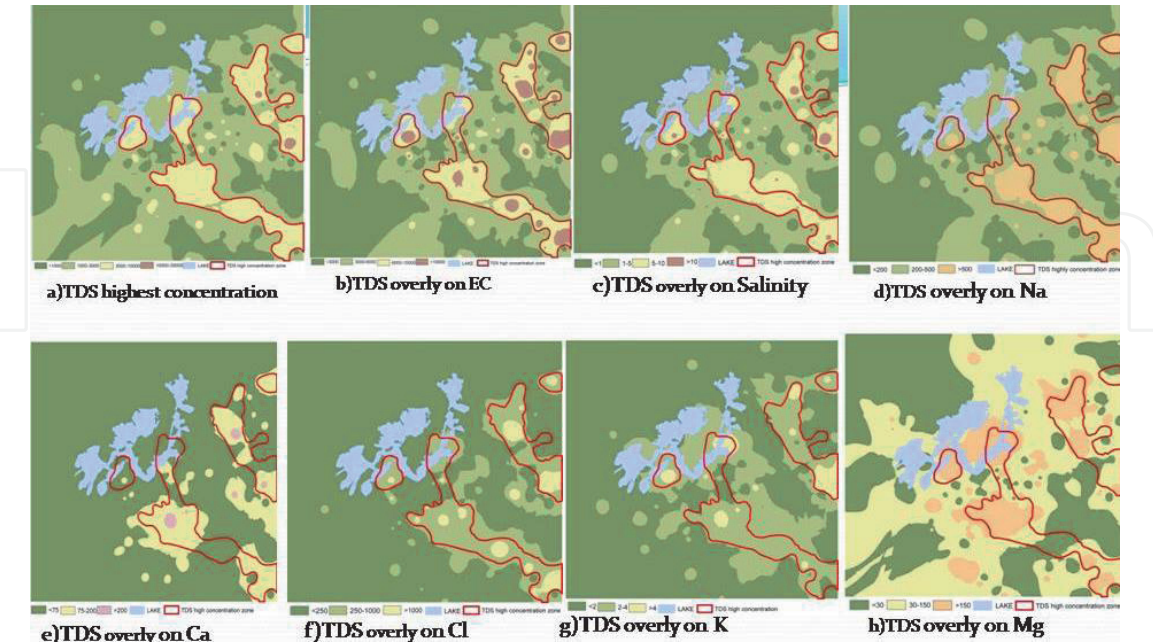
### 3.3 Resistivity survey

Electrical resistivity survey is one of the best technique to demarcate aquifer composition, groundwater, bedrock, and fresh/salt zones [10]. To delineating the





**Figure 5.**  
*Hydrological map of Kolleru catchment.*



**Figure 6.**  
*Comparison of TDS high concentrations with other parameters.*

shallow and deep aquifers using with Schlumberger configuration were made in the recent past [11, 12]. In this work the same method has been utilized to demarcate interface of different natures of water. The additional leaky or fissured a rock,



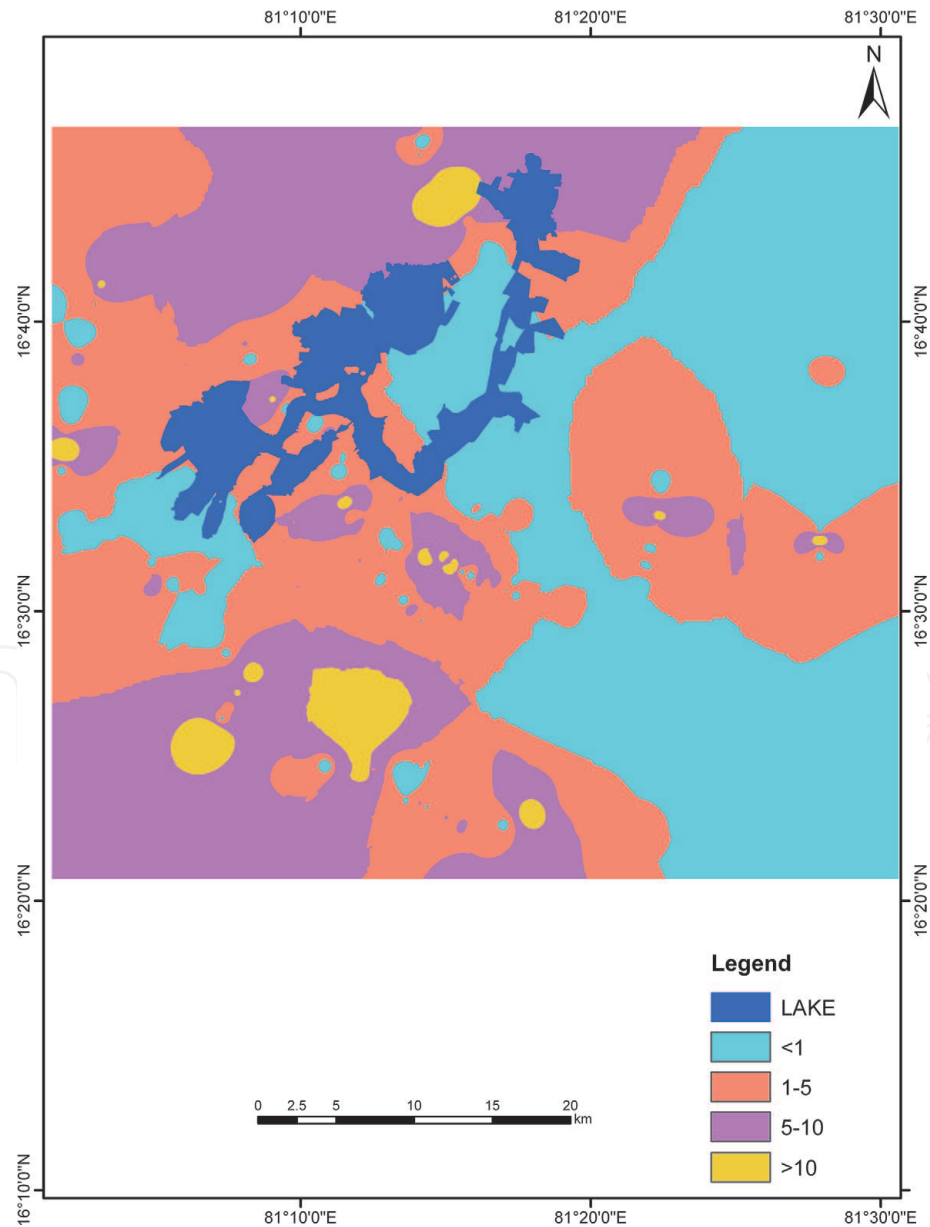
the lower the resistivity. Higher degree of saturation or greater amount of water presents in pore spaces and fissures also decreases the resistivity [13].

Top soils are having resistivity varies between 3 and 68 ohm-m in paleo beach ridges, lake plain and uplands. Flood plain deposition, marine lagoon plain and marine built plain having top soil resistivity varies between 2 to 27, 1 to 15 and 0.3 to 15 ohm-m, respectively. Paleo beach ridges which are having fresh potable water is having top soil resistivity between 8 and 50 ohm m. Spatial distribution of top layer resistivity has shown in **Figure 7**.

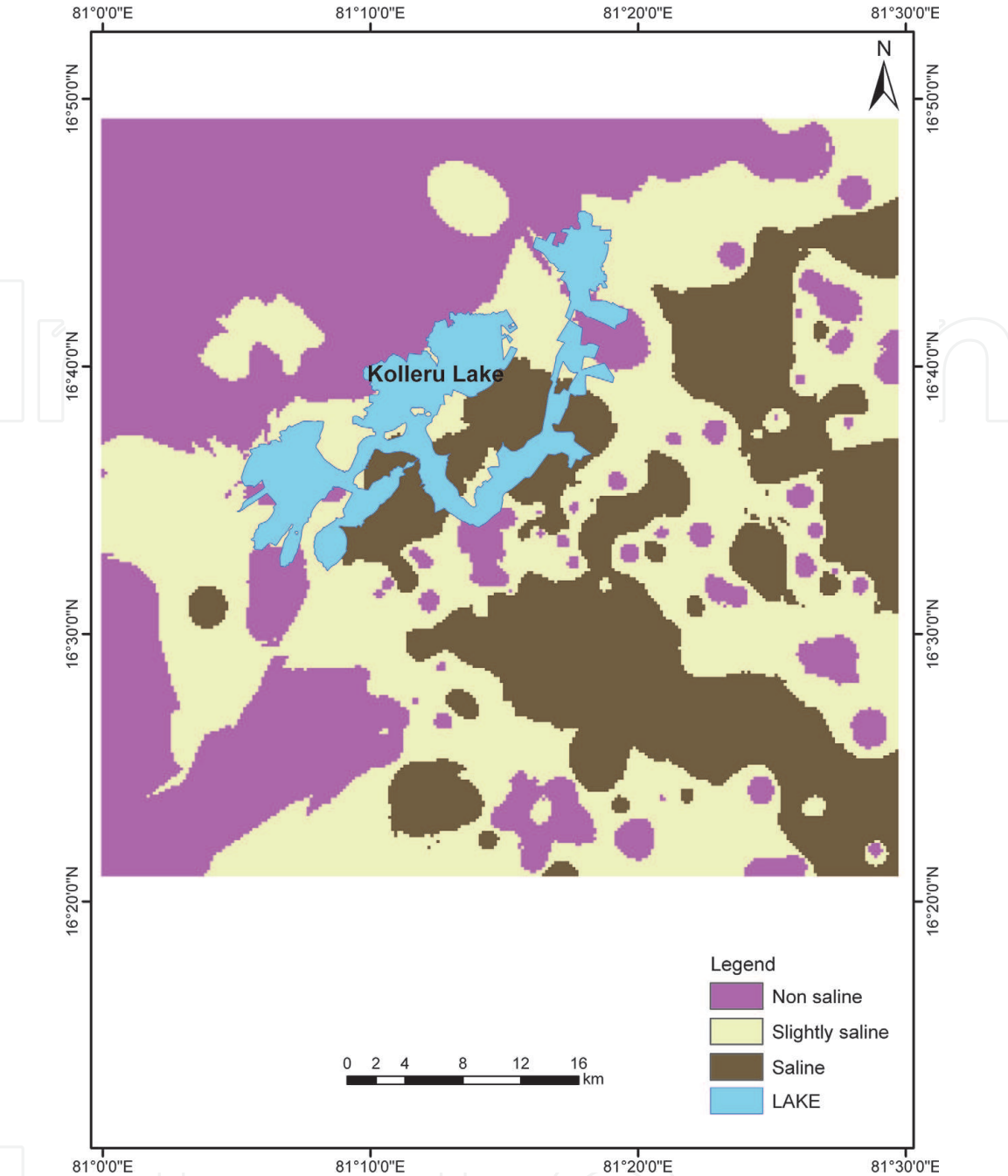
In the present chapter, geophysical resistivity studies and chemical analyses of ground water of different open wells are compared. Finally, an attempt made to compared analysis of Vertical Electrical Soundings (VES) data and chemical data of observation wells nearby sounding resistivity location which are more related.

3.4 Integration

Geographical Information system (GIS) is one of the best tool to identify salt water intrusion zones [14]. The heavy concentration of saltwater in ground water is represented the form of a map using weighted overlay techniques of ArcGIS.



**Figure 7.**  
*Spatial distribution of top layer resistivity.*



**Figure 8.**  
*Broad classification of groundwater as per the integration of hydrochemical data and electrical resistivity.*

Another important aspect of geographic information system (GIS) is that it enables the analysis of the spatial data and their attributes contained in the database. We have analyzed all the data layers through the process called “Overlay” in ArcGIS 9.3. Index Overlay is a best spatial action in which superimposed of many thematic layers onto another to form a new layer. This kind of overlay is also called “Arithmetic overlay,” which means that values assigned to two or more input themes are combined arithmetically (+, −, \*, /) to produce an output grid [15].

In this case the map classes existing on each input layers are assigned different scores, as well as the maps have to assign different weights as before. It is suitable to describe the scores in an attribute Table for each input map. The averages score is than defined by the equation

$$\bar{s} = \frac{\sum_i^n s_{ij} w_i}{\sum_i^n w_i}$$

where

$\bar{s}$  = Weighted score for an area object (polygon, pixels)

$S_{ij}$  = Score for the  $j$ -th class of the  $i$ -th map

$W_i$  = Weighted score for the  $i$ -th map

Binary map analysis, Fuzzy logic and Index Overlay with Multi-class maps are some other methods available to determine inter class dependencies or inter map dependencies. Here an attempt has been made to use multi class maps in Index overlay method [16].

The input layers which are considered for the analysis of groundwater vulnerability zones are Salinity, TDS, Resistivity, EC, TH, Na, Cl, Ca, Mg, K,  $\text{NO}_3$ ,  $\text{SO}_4$ , TA and  $\text{pH}$ .

To calculate sum of weighted conditions and divided by normalization factor

New Vulnerability Map =

$$\frac{[*M1 + *M2 + *M3 + *M4 + *M5 + *M6 + *M7 + *M8 + *M9 + *M10 + *M11 + *M12 + *M13 + *M14]}{\text{SUM}}$$

According to the levels of concentrations of these chemical parameters and resistivity of the top layer in the study area these were given with a fastidious weightage number and operated to obtain a map which is used for further analysis. Hence, calculated the each grid cell data and represented in the form of map showing the saline and non-saline groundwater zones in **Figure 8**. Fresh ground water is available in uplands, flood plains and paleo beach ridge zones. The areas of paleo lagoons (**Figure 8**), marine plains, marine marshy lands shown in the non potable groundwater zones. Saline groundwater zones broaden into the lake area and the continuous big brown patch between lake and the coast may be the main route of salt water intrusion towards the land. There are several potable groundwater patches in pink color close to the coast which may be due to presence of sand dunes that hold the fresh water.

## 4. Conclusion

The results of this study clearly indicate that the sea water intrusion is taking place on both sides of the Kolleru lake through paleo channels. One big seawater intrusion zone was identified along the Upputeru river of 40 Km length from the coast to Lake. 70 out of 174 groundwater samples are non saline (40.2%), 37 samples are slightly saline (21.3%) and 67 samples are saline (38.5%). These statistics shows that potable groundwater is present in 40% of the total well locations. Most of the freshwater wells existed in the uplands of Kolleru Lake. Iso-resistivity contours of vertical cross sections clearly indicate the fresh and salt water zones. Areal mapping of fresh water aquifers (2023 sq.km) and sea water intrusion (784 sq.km) are also demarcated.



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